Charge for the Readiness Review of LRS01

The committee (Jim Kerby, Tom Taylor, Fred Nobrega, Arup Ghosh and Al Lietzke) met April 24-25 at LBNL, covering material presented to us before the review, presentations given by the proponents during the review, and extra discussions during the review period. We thank the team for their open responses, and have included our comments in italics below interspersed with the charge that was given to us.

The goals of the Long Racetrack RD are:

1. To test 3.6m long Nb3Sn coils fabricated with the same technology that will be used for the coils of the Long Quadrupole.

2. Coils will be tested in an Al-shell-based supporting structure (preloaded using bladders and keys) in order to verify the use of this concept for long magnets.

We plan to achieve the first goal in two steps: the coils of the 1st Long Racetrack (LRS01) will be fabricated with the same technology of LBNL-SM (small magnet) series, except for a few modifications necessary for long coils. The coils of the 2nd Long Racetrack will be fabricated with the same technology to be used for the Long Quadrupole coils.

We ask you to review the design and the plan for fabrication and test of the LRS01, including both coils and supporting structure.

The committee thanks and congratulates the team for their efforts to prepare for this review and for the fabrication of LRS01. Certainly great progress has been made since the Santa Rosa meeting. Presentation of the integration of the LR instrumentation and the stated goals of the LR program are improved from previous reviews.

Here there are a few questions we would like you to address:

- Are LRS01 design and plan consistent with the goals?
  - *The primary goal as stated is the check that long Nb_3Sn coils can be fabricated w/o degradation. In this case, "Degradation" needs to be clearly defined—what is the metric (to SRS01, to extracted strand, or to virgin strand)? This is the primary goal and from the standpoint of the test plan this is where all resources should be focused first. All other things are secondary studies.*
    - *To be clear, the common coil test only checks that degradation occurs at the middle of the coil in the high field regions. The test method is not sensitive to degradation in many areas of the coil, including outer edge*

turns, pole turns, and the ends. Success of this test does not completely prove the design for use in the LQ design.
    - *Within the limits of this test, a result of "no degradation" will prove out the fabrication, impregnation, and thermal contraction assumptions used to make the LRS coils. Instrumentation and QA plans have to be set up to be as traceable as possible back through the construction process.*
    - *In the case of success of LRS01, we think that more information for the LQ series could be extracted with relatively little extra work if the coil were to be excited as a dipole with appropriate support (in a steel box). We note that the design of such a structure exists, and it is already planned to make an analogous test on a subscale racetrack.*

The committee notes that the objective of any R&D plan should be to maximize the information gained from each coil, as each involves a large investment. To that end, the incremental gains and costs associated with alternative field configurations should be explored, and may help answer questions that the current LR program will not address. In addition to the test of the successful LRS01 coils in a dipole mode, other possibilities might include:
    - *Inverting the Layer-1 and Layer -2 order to test the low-field layer for degradation in the high field location*
    - *Shaping the flux return reluctance to facilitate easier conductor degradation measurements of edge turns*

- *Other goals include*
    - *Fabrication of ~350m Nb3Sn cables*
    - *Insulation of long Nb3Sn cables*
    - *Winding and handling tooling and procedures*
    - *Pole gaps to limit final gaps created during reaction (note LRS01 has an iron pole like SRS01, while later are bronze)*
    - *Check of the quench protection (and quench heaters w/ the printed voltage tap method/design)*
    - *Check of coil impregnation methods and epoxies*

- Are LRS01 design and plan sound and complete? We ask you to look at all parts of the design and plan: magnetic and mechanical design, quench protection, instrumentation and test plan.
    - *Magnetic and Mechanical design are complete. Frictional effects in the 3-D model might be explored more.*
    - *The utility of the pins in the yoke was not immediately clear to the committee.*
    - *The choice of iron for the island is question: as it has to be in sections it will in any case differ from the first short racetrack, it may be advantageous to make a second short racetrack with non-magnetic island material that could be a candidate for the LQ coils and then proceed to the long racetrack fabrication.*
    - *Quench protection – not yet complete but should be able to converge. Redundancy and failure modes should be reviewed.*

- *Instrumentation – Preliminary map was just added to Design Report. This will need to be finalized w/ time for artwork and execution. Integration of this with the quench heater has not been done before at this scale.*
- *Reaction oven commissioning plan looked OK.*
- *The plan for reaction tooling stress relieving was not reviewed, and should be done at the manufacturer before initial inspection. We suggest an additional inspection after use of the tooling during oven commissioning, but before fabrication of the first coil, to best ensure that bend and twist are minimized before reaction of the first coil.*
- *A plan for checking the impregnation of the copper practice coil was not in place at the time of this review.*
- *A voltage test on a coil made with sleeve insulation will not be possible until the first actual coil in the current plan.*
- *Test plan – OK. There is a limit on BNL test facility temperature variation. Depending on SRS results an additional test at FNAL or LBNL may give additional results. Shipping of LRS elsewhere is a concern.*

- Is the analysis adequate and the design consistent with the results?
  - *Magnetic / mechanical analysis is very complete. The committee had secondary questions on*
    - *Why the 3D mechanical model looking at longitudinal effects was shorter and if this mattered in the w/ friction case*
    - *What coil, iron, and bronze thermal contraction properties were used and what the sensitivity of the results were to these values*
    - *What the difference will be when the iron island is replaced with a bronze island. Minimizing shear motion between the coil and the island is a legitimate goal, and the LRS team should investigate and document their plan to achieve this goal through material selection, segmenting of the island, or other means, and verify the analysis during the course of the LR tests.*

- Have all length related issues been addressed in the design and in the plans for coil fabrication and magnet assembly?
  Careful integration and understanding of the needs of the LQ program, the results from the LR program, and how the two mesh in a timely manner are an important task for LARP Magnet management.
  In response to the question the committee restates the length effects that are addressed by the current LRS program, and those that are not, but that may still be important to LARP and the LQ program. LARP may consider how these other items will be addressed within the scope of the LR program or some other portion of the overall program.
  - *LRS01 does not cover end load and support*
  - *LRS01 does not cover wedge breaks (though they could be expected to be similar to the island values)*
  - *LRS01 does address assembly fabrication issues for a given design.*
  - *LRS01 partially addresses contraction fabrication issues for the given design.*

- Are we ready to start the fabrication of LRS01? Is there any issue that should be addresses before starting fabrication?
  - *Given the upcoming results from SRS01, the fabrication and delivery of various parts and tooling, and the inspection and commissioning of those parts and tooling, the committee feels the program should keep proceeding.*
  - *We do feel that several commissioning plans and detail designs should be more carefully documented. These include*
    - *The impregnation checks*
    - *The reaction tooling inspection*
    - *The pole island gap analysis*
    - *The instrumentation plan*
    - *Definition of success for the coil degradation*
  - *The committee emphasizes that since this is an R&D effort, careful and thorough QA documentation will be critical in the effort to understand test results.*

- Please, add any comment or suggestion that in your opinion may help to increase the probability of success of LRS01, and/or help to achieve the Long Racetrack R&D goals.
  - *What is the formal plan for cable acceptance? This should be addressed by the LARP materials group.*
  - *Extend the initial 'what if' analysis to include 'success' in the LRS01 test and how the program might be extended in this scenario.*
    - *For instance, a mirror race track configuration could test other regions of the coils for degradation and coil prestress / end load effects*
    - *If the LRS01 test is a success, we believe the possibility of exciting the coils as a dipole should be considered by the LRS team.*
  - *We encourage the proponents to become more proactive as the LRS program goes forward, and use this review as a starting point for continued integration of the LRS team with a focus on maximizing the technical answers gained from the effort.*